

Assessing Hydro-Oceanography Conditions Using Delft3d Numerical Model For Lampia Port, Bone Gulf, Indonesia

Bayu Wintoro^{1*}, Munawir Bintang Pratama², Alvin Yesaya³, Amirah Zakiyyah¹

^{1,4}Bandung State Polytechnic (Politeknik Negeri Bandung), Bandung, Indonesia

²University of Edinburgh, Scotland, United Kingdom

³University of Udayana, Jimbaran, Indonesia

*E-mail address: bayu.wintoro@polban.ac.id

ABSTRACT

Lampia Port is part of the Coastal Area located in The Bone Gulf, Central Sulawesi, and serves as one of the docking ports for passenger and cargo loading and unloading activities in Central Sulawesi. This study was conducted to identify the tidal, current, and erosion/sedimentation characteristics in the coastal waters around the port as parameters for planning the rehabilitation and development of the port. Tidal, current, and erosion/sedimentation analyses were performed using numerical modeling on the Delft3D-FLOW and Delft3D-WAVE modules of the Delft3D software developed by Deltares. The data used in the modeling include bathymetry and local tidal elevations obtained from field surveys. The modeling was carried out using the nesting method with three levels of grid resolution, with the highest resolution at 43 x 43 m² approaching the Coastal Waters of Lampia Port. The modeling results were validated with field data in the form of tidal elevations at two points in the coastal area around the study location. The modeling results indicate that the tidal range in the Lampia Coastal Waters reaches 3,54 meters with a mixed – semi-diurnal type. The modeling results also show the current patterns in the Lampia Coastal Waters with estimated magnitudes ranging from 0.5 m/s to 1 m/s. Additionally, erosion/sedimentation patterns around Lampia Port range between 3-10 cm per year.

Keywords: numerical models, wave transformation, hydrodynamics simulation, and transport sediment.

1. INTRODUCTION

Erosion of the coastal seabed, ultimately leading to shoreline retreat, is caused by a combination of the aforementioned processes and has significant implications for the economy, environment, and community safety, as many critical activities and infrastructure are concentrated in coastal zones [1]. Such changes can disrupt fisheries, tourism, shipping routes, and coastal settlements, while also increasing vulnerability to flooding and storm surges.

Coastal engineering addresses key aspects such as wave dynamics, sediment transport, and management strategies, with advanced three-dimensional models developed to simulate tide- and wind-driven currents as well as wave-induced sediment resuspension [2]. Research in this field covers wave theories, nearshore currents, coastal structures, and sediment transport

(Smith, 2002, 2008), and also examines long-term influences such as tidal patterns, seasonal variations, and the impacts of climate change on water levels, which are crucial for sustainable coastal planning and protection.

Determining hydro-oceanographic parameters—wave height, period, current speed, and sedimentation rate—is essential for effective port planning to minimize ship disturbances and dredging needs. However, in many locations, environmental data is limited, making accurate design challenging. While satellite data can provide valuable insights, its coarse spatial resolution ($\sim 50 \text{ km}^2$) often results in inaccuracies for smaller target areas ($< 2 \text{ km}^2$). Therefore, numerical model simulations are needed to produce detailed, site-specific information that supports engineering decisions and long-term maintenance strategies.

This study focuses on Lampia Port, South Sulawesi, Indonesia, located in Malili District, East Luwu Regency. Classified as a Collecting Port until 2037 under the National Port Master Plan (RIPN) in Minister of Transportation Regulation KP.423/2017, the port is situated approximately 20 km from Malili City. Construction began in 2010, and after years of development, the port officially commenced operations in 2018. Given its strategic location and role in regional trade, Lampia Port serves as an important case study for assessing hydro-oceanographic conditions and sediment transport dynamics in support of port efficiency and coastal management.

2. THEORY AND METHOD

Predicting erosion and sediment transport requires a thorough understanding of sediment processes in surface water systems [3]. This research focuses on tides, wind, wave hindcasting, and numerical modeling. Coastal engineering has made significant progress in studying wave dynamics, sediment transport, and coastal protection mechanisms. Goda (2000) emphasizes advancements in assessing wave pressures, analyzing wave transformations, and modeling sediment transport, while Sawaragi (1995) provides an in-depth discussion on wave–structure interactions, their influence on sediment dynamics, and practical applications of various coastal structures. Variations in seawater levels caused by atmospheric (pressure, wind direction, and velocity), hydrological (river basins), and tidal factors make obtaining accurate water level data essential in hydrographic surveys [5]. Karambas & Samaras (2017) introduce a comprehensive and reliable numerical model for simulating wave propagation, circulation, and sediment transport, proven effective in both laboratory and field conditions [6]. Quick (1983) explores sediment transport under combined wave–current influences, establishing a transport power relationship to estimate movement rates [7]. Collectively, these studies highlight the complex interactions between waves, currents, and sediment behavior, providing valuable insights for the design and implementation of effective coastal protection strategies. Furthermore, the presence of a sediment source or sink can enhance accretion or erosion trends, as seen in port siltation caused by sediment discharge from nearby rivers [8].

2.1 Tidal Theory

Tides are predictable and are expressed using tidal harmonic constants. A description of the nine primary tidal harmonic constants is provided in Table 1. Semi-diurnal constants are tidal constants that produce two tidal events in one day, while diurnal constants produce one tidal event in one day.

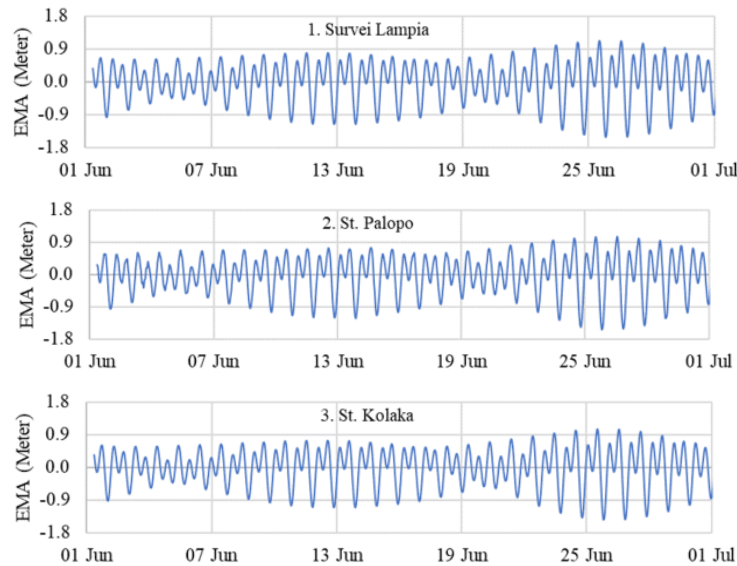


Figure 1. Water Level Elevation from Lampia Surveying, St. Palopo, and St. Kolaka (2021).

Table 1. Main Harmonic Constant of Tidal from the Analysis

Name	Symbol	Period (hour)	Name	Symbol	Period (hour)
Semi-diurnal			Diurnal		
<i>Principal lunar</i>	M2	12.421	<i>Declination luni-solar</i>	K1	23.934
<i>Principal solar</i>	S2	12.000	<i>Principal lunar</i>	O1	25.819
<i>Elliptical lunar</i>	N2	12.658	<i>Principal solar</i>	P1	24.066
<i>Declination luni-solar</i>	K2	11.967	<i>Shallow water over tides of principal lunar</i>	M4	6.21
			<i>Shallow water quarter diurnal constituent</i>	MS4	6.10

2.2 Wave Hindcasting Theory

The most common method used to determine wave characteristics and height at a location is wave hindcasting [9]. Wave hindcasting is a technique for predicting sea wave heights using hourly wind data, which is then converted into wave height and period at sea. In general, waves that occur in the sea are caused by the friction between wind and the sea surface, which forms waves [10]. The important factor of hindcasting method is calculating wind data and wave generations area. Figure 2 shows the calculation of hindcasting and fetch from the target location. The parameters u_A , F , g , and t represents the wind friction coefficient, fetch, gravitational constant, and wind duration, respectively. The value of u_A is derived from the wind speed value that has been corrected for elevation, duration, location, temperature, and stability following the CEM 2008 method.

Fetch (F) is obtained by drawing a line from the wind data point to the nearest land for every 5 degrees. An illustration of how to draw fetch is given in Figure 2. The fetch for eight wind directions is determined using the effective fetch formulation below. A table of individual fetch values for each fetch-ray per wind direction is given in Table 2. The fetch area must be calculated from all directions, and its magnitude can be calculated using the following formula:

$$F_{Effective} = \frac{\sum F_i \cos \theta_i}{\sum \cos \theta_i}$$

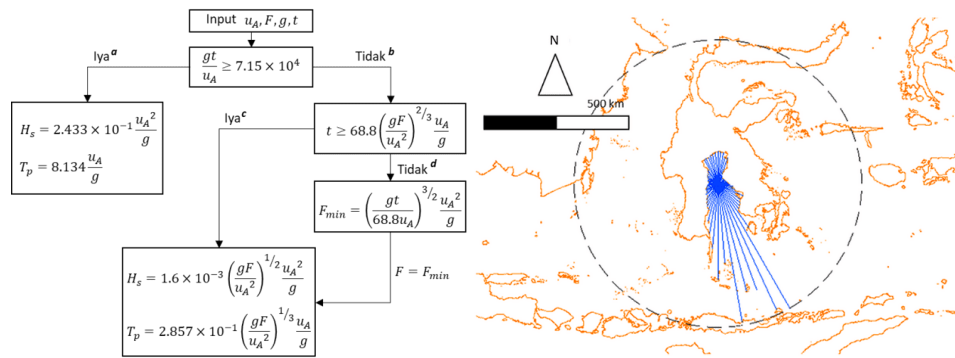


Figure 2. Hindcasting and Fetch method (*Shore Protection Manual 1984*)

Table 2. The effective fetch length for each direction

Effective Fetch (km)							
E	NE	N	NW	W	SW	S	SE
44.74	28.30	114.98	64.15	39.27	66.55	309.12	212.63

The results of the hindcasting analysis were then compared with data from the BIG wave model and wave data compiled from ERA5. The data from BIG and the ERA5 data for locations within Bone Gulf provide similar value ranges, but both indicate that the wave height in Bone Gulf is predominantly below 0.5 meters.

2.3 Numerical Modelling

Numerical model in this study is using Delft3D, developed by Deltares, is one of the most widely used hydrodynamic modeling software in the world. Delft3D can be used to simulate currents, sediment transport, waves, and in other case studies. Delft3D has been widely applied for studies in coastal, river, lake, or estuarine areas.

Delft3D is divided into several modules based on its functionality and can be run separately or together (coupling). The two most commonly used modules are Delft3D-FLOW and Delft3D-WAVE. Flow module is used to model the fluctuation of tidal elevation and currents based on the unsteady shallow water equation, which consists of the continuity equation and the momentum conservation equation. This module models tides by considering barotropic effects, Coriolis forces, wind, water bottom roughness, and other generating forces and wave module is used to model waves using the spectrum method based on the action balance equation. In simulating wave propagation, this module considers wind-generated wave generation, wave energy dissipation (white capping, water bottom roughness, and breaking waves due to depth), and nonlinear interactions between waves.

2.4 Data Collection

The data collection method used in this research is a combination of primary (field) data and secondary (reference/literature) data. The primary data used is tidal observation data, which will be used to validate the numerical model.

3. RESULTS AND DISCUSSION

3.1 Wind and Tidal Analysis

The wind direction in the Bone Gulf can be seen in the Figure 3 below.

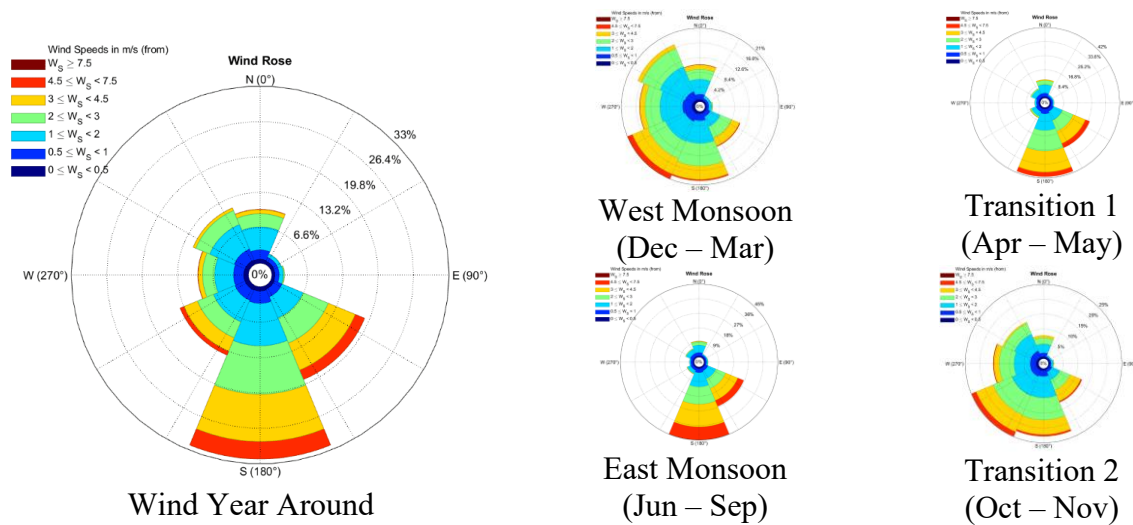


Figure 3. Wind Rose 20 years in Bone Gulf

Table 3. The Analysis of Harmonic Constant

Constant	Lampia Surveying		St. Palopo		St. Kolaka	
	Amp. (m)	Phase (°)	Amp. (m)	Phase (°)	Amp. (m)	Phase (°)
M2	0.601	310.1	0.583	308.7	0.534	19.7
S2	0.234	109.9	0.250	107.6	0.224	170.8
N2	0.129	250.7	0.129	249.9	0.126	326.9
K2	0.130	108.6	0.138	101.8	0.139	166.1
K1	0.204	328.6	0.198	329.3	0.195	176.7
O1	0.202	208	0.204	211.7	0.204	70.6
P1	0.221	306.9	0.221	304.1	0.210	152.2
Q1	0.052	161.9	0.053	160.2	0.053	22.8
Formzhal	0.486		0.483		0.526	
Type	Mixed Semi-diurnal		Mixed Semi-diurnal		Mixed Semi-diurnal	

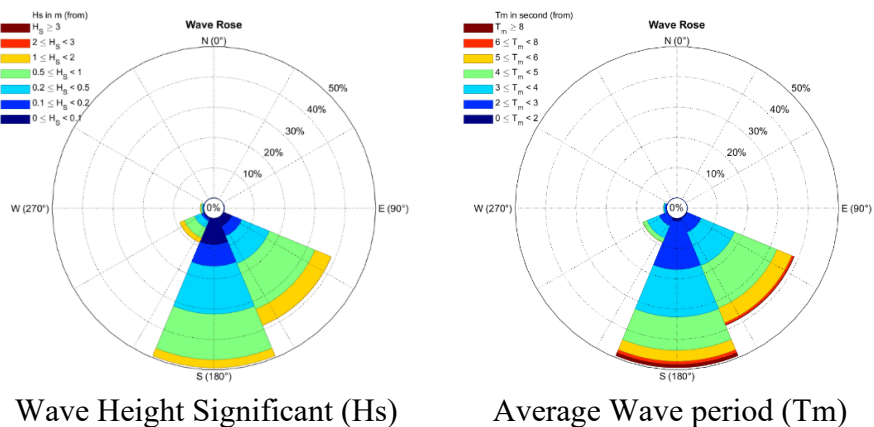
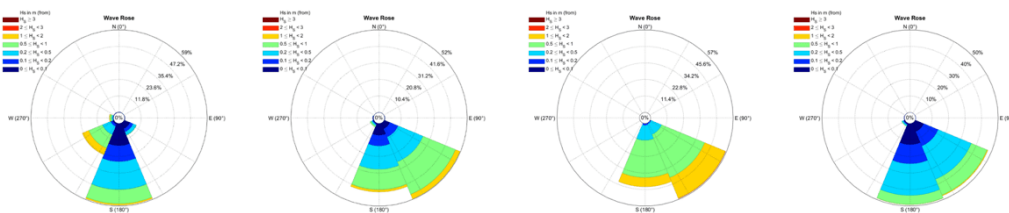
Table 4. Elevation in Lampia Port

Elevation	Datum MSL (m)	Datum LAT / LWS (m)
HAT	1.773	3.546
HHWL	1.591	3.364
MSL	0.000	1.773
LLWL	-1.591	0.182
LAT	-1.773	0.000
Tide	3.546 meters	

3.1 Wave Data Compilation from ERA5

Waves were compiled from offshore or in the Bone Gulf area (3.75°S, 120.75°E) over a duration of 20 years, from 2001 to 2021. Data visualization in the form of a wave rose diagram is provided in Figure 4, with the following summary:

- Dominant waves come from the South and Southeast, with dominant heights and periods ranging from 0.1 m to 1 m and 2 seconds to 5 seconds.
- Maximum, average, and minimum wave heights are 2.71 m, 0.51 m, and 0.01 m.
- Maximum, average, and minimum wave periods are 14.93 seconds, 3.87 seconds, and 1.33 seconds.

**Figure 4.** Wave rose for observation points in Bone Gulf over 20 years.

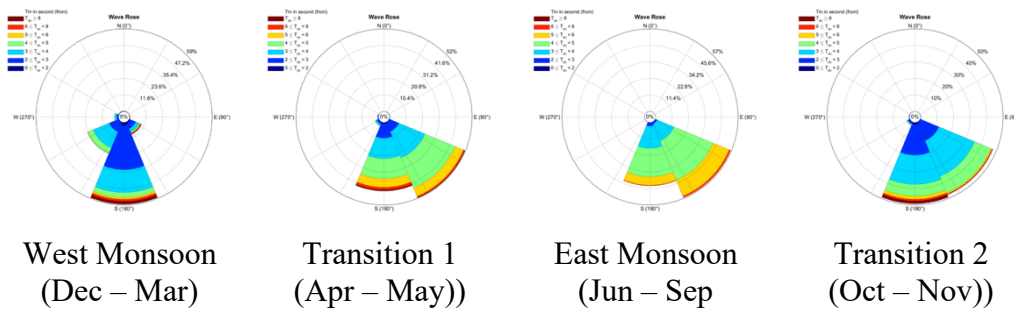


Figure 5. Wave rose for wave height (Hs) west monsoon, transition 1, east monsoon, and transition 2 period

3.2 Numerical Model Results

3.2.1 Domain Configuration

The domain and bathymetry of the tidal model, specifically for the Bone Gulf and Lampia Port domains, are shown in Figure 5. Detailed specifications and configurations for each domain are provided in Table 5. In the Bone Gulf domain, the grid resolution is uniform. Meanwhile, in the Lampia Port, the grid resolution is designed to be gradually finer from offshore towards the waters around Lampia Port.

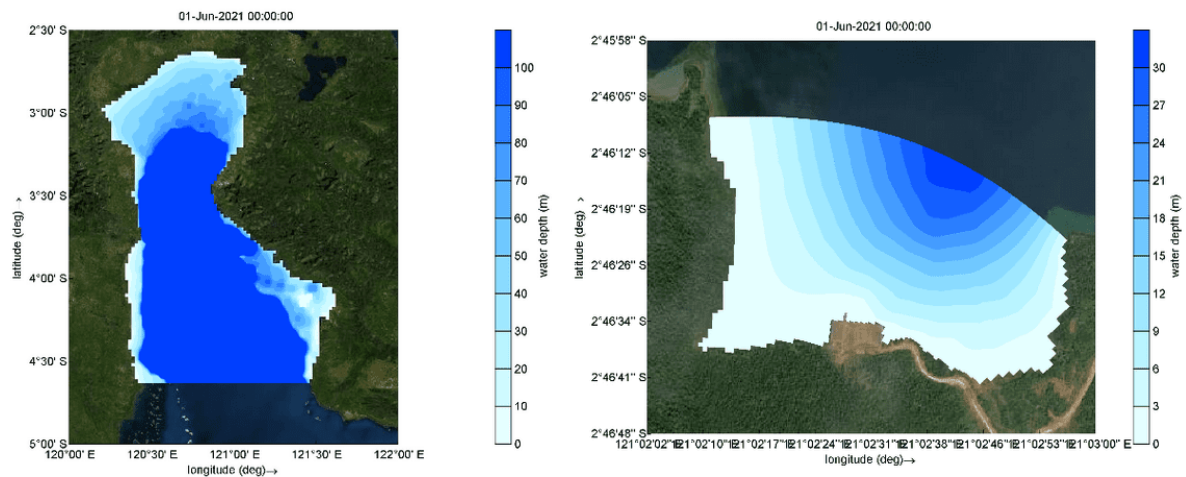


Figure 6. Bathymetry Domain for the Bone Gulf and Lampia Port

Table 5. Domain Configuration for the Model

Parameters	Domain The Bone Gulf	Domain Lampia Port
Grid Resolution (m ²)	2,224 x 2,224	Ranging from 32 x 19 to 4 x 6
Nodes	7,696	8, 424
Area of Interest (km ²)	168.2 x 228.0	2.1 x 1.5
Boundary Condition	EMA predicted by BIG and ERA5	Output from the Bone Gulf

3.2.2 Model Calibration

The data collection method used in this research is a combination of primary (field) data and secondary (reference/literature) data. The primary data used is tidal observation data, which will be used to validate the numerical model.

The comparison between the model data (D3D) and field observations (OBS) is provided in Figure 7. The model can produce water surface elevation values similar to those observed in the field at BIG measurements at the Palopo and Kolaka Port Station. The correlation coefficient r at the three locations is close to 1 (~ 0.994), indicating a positive correlation between the two data sets. The RMSE values at both locations are low (~ 0.054), indicating a small difference between the two data sets. With $r > 0.95$ and $RMSE < 0.100$, the model can be considered reliable.

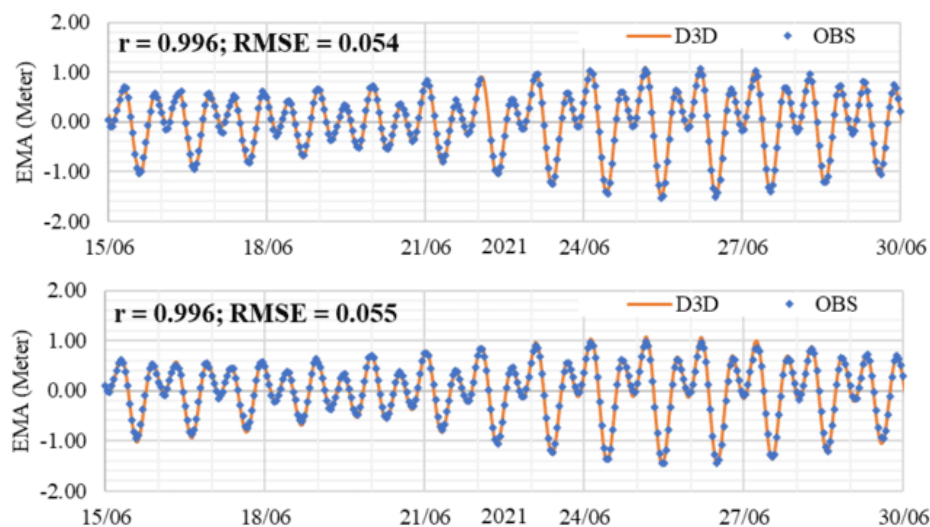


Figure 7. Model Validation at St. Palopo (above) dan St. Kolaka (below)

3.1.3 Wave Numerical Model Result

To determine extreme waves in Lampia Port, extreme wave and wind conditions are input into the Bone Gulf domain. Models for 50-year and 100-year return periods are simulated based on the dominant direction that produces the highest wave heights. The input values for extreme waves and winds are provided in Table 6.

Table 6. Input values for extreme waves and winds

Return Period (years)	Waves			Wind	
	H (m)	T (s)	Direction (°)	u (m/s)	Direction (°)
50	2.98	13.47	157	8.57	232
100	3.23	13.93	157	8.85	232

Figure 8 shows the wave propagation pattern for the 50 and 100-year return period wave conditions coming from the Southeast. The wave height at Lampia Port is around 20-30 cm.

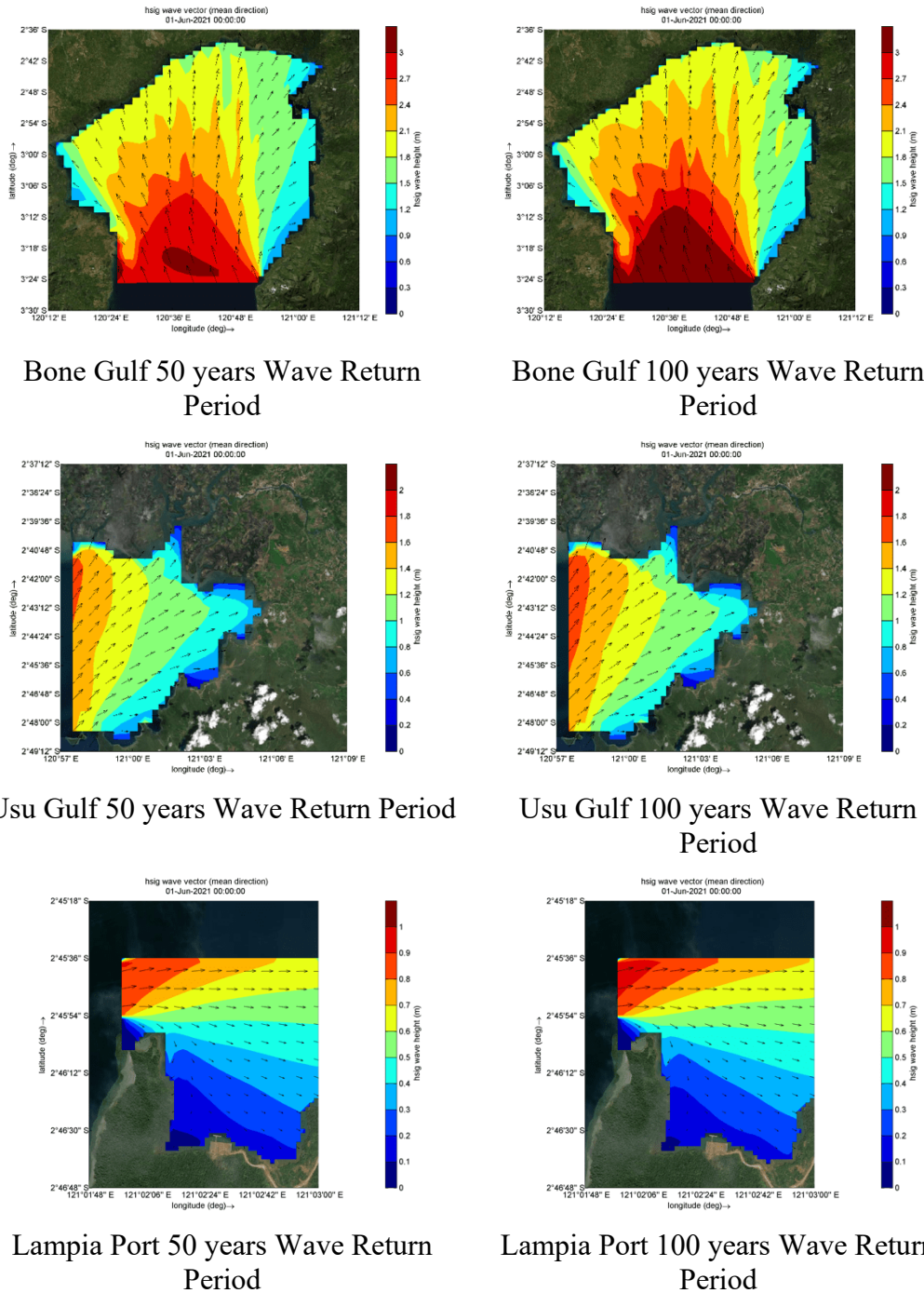


Figure 8. Wave height patterns in Bone Gulf, Usu Gulf, and Lampia Port in the direction coming from the Southeast in the 50 and 100-return period.

3.2.3 Hydrodynamic and Sediment Transport Model Result

The result of the tidal patterns has been divided into 4 parts during the highest spring tide, lowest spring tide, highest neap tide, and lowest neap tide. The four conditions are shown in Figure 9. Four observation points of the tidal pattern, with red and blue diamond indicating the high and low tide phenomena to be observed. The hydrodynamic tidal patterns (water level elevation and currents) for each condition are provided in Figure 10 and Figure 11.

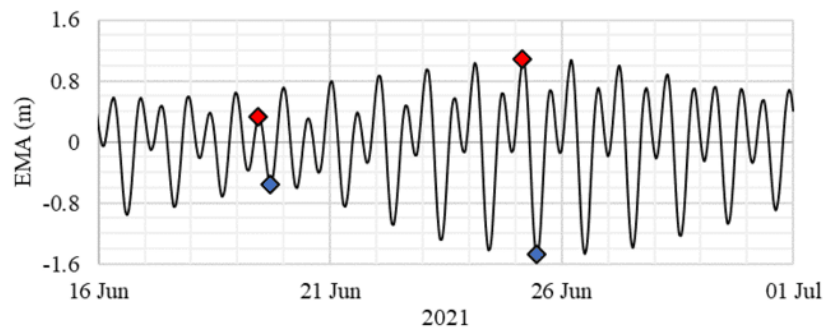
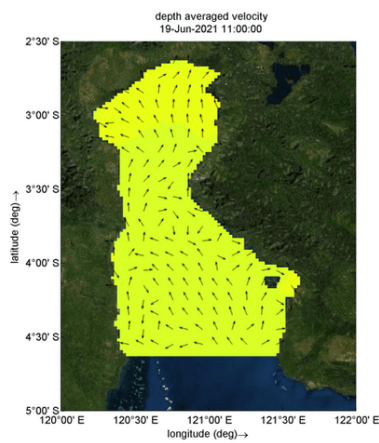
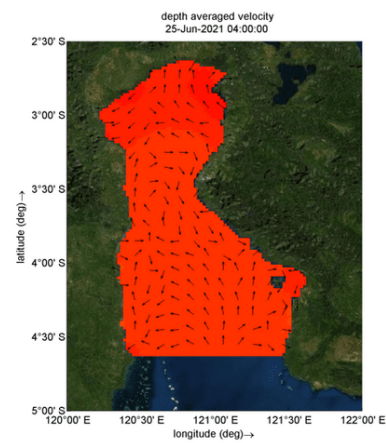


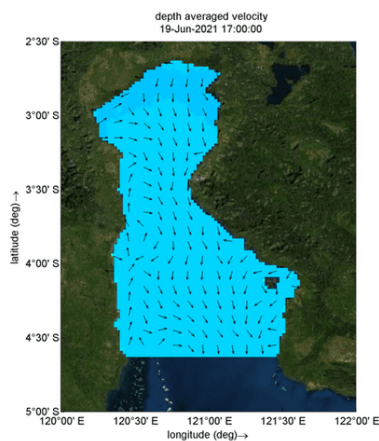
Figure 9. Four observation points of the tidal pattern



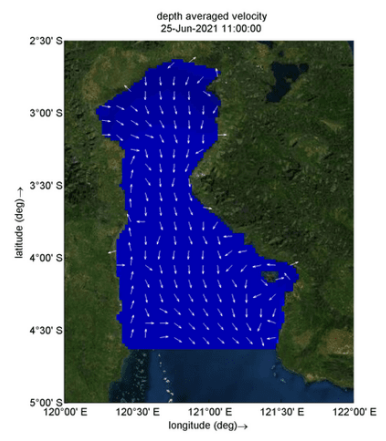
Hydrodynamic pattern of spring tide, June 19 2021 11:00



Hydrodynamic pattern of neap tide, June 25 2021 04:00



Hydrodynamic pattern of spring low tide, June 19 2021 17:00



Hydrodynamic pattern of neap low tide, June 25 2021 11:00

Figure 10. Tidal patterns and currents in Bone Gulf waters

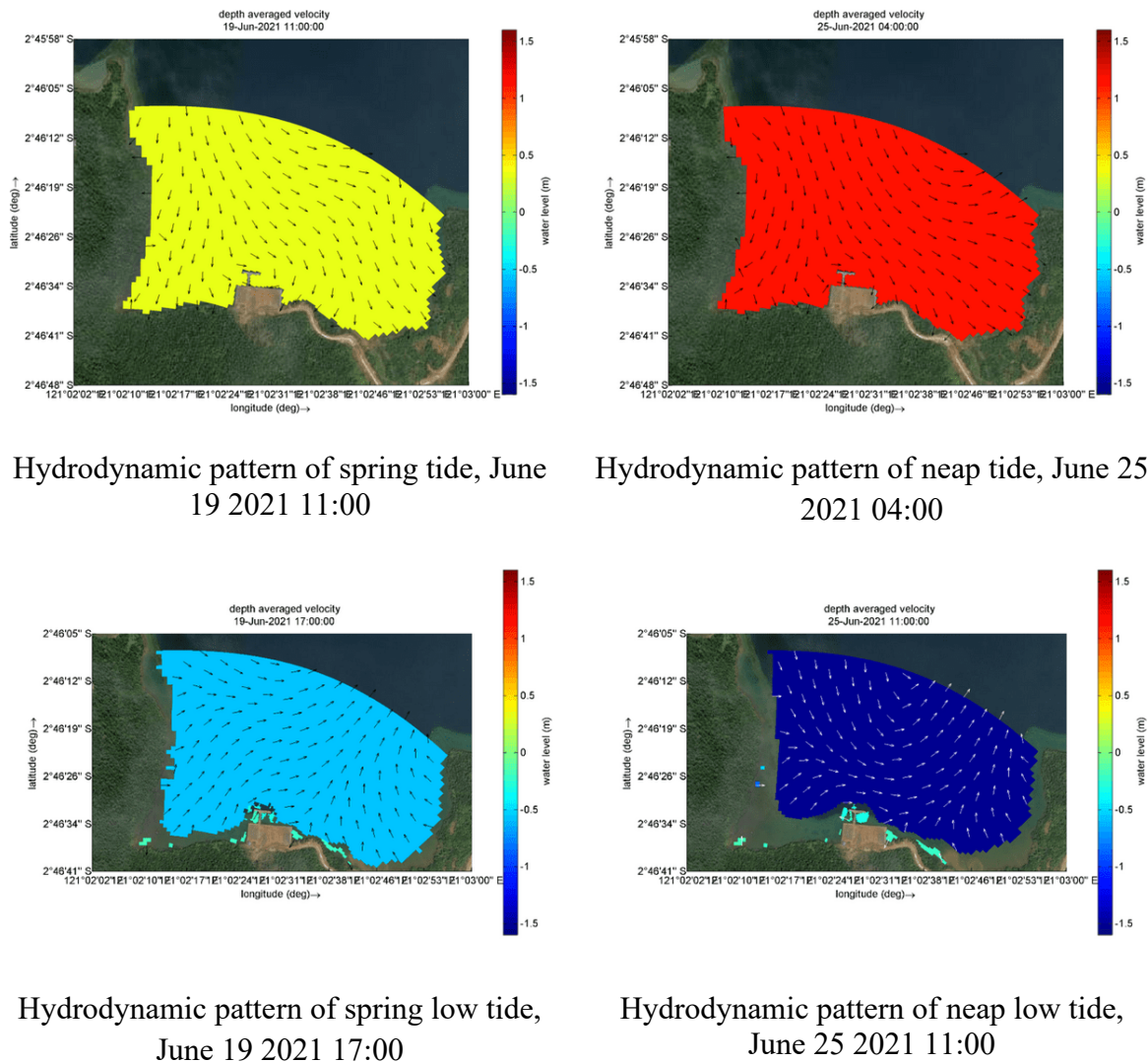


Figure 11. Tidal patterns and currents in Lampia waters

Sediment transport in Lampia Port was simulated using the Delft3D-FLOW and Delft3D-WAVE modules running in a coupled mode. The sediment transport model calculates the erosion and sedimentation patterns caused by sea currents (tides and waves). To provide a more accurate representation of currents, the Delft3D-FLOW module was configured in three dimensions.

The sediment transport model was simulated over the course of one year. The modeling results are shown in figure below. Based on **Figure 12**, Sedimentation in the Lampia waters is assessed as stable, with the majority of the domain experiencing less than 10 cm/year of erosion or sedimentation. The western side of the Lampia waters experiences relatively minor erosion/sedimentation, approximately 4 cm/year. The eastern side of the Lampia waters experiences erosion/sedimentation of approximately 8-10 cm/year. The area behind the dock and jetty of Lampia Port experiences sedimentation of about 3 cm/year. From the analysis, it can be concluded that maintenance dredging is not required at the port location for the foreseeable future.

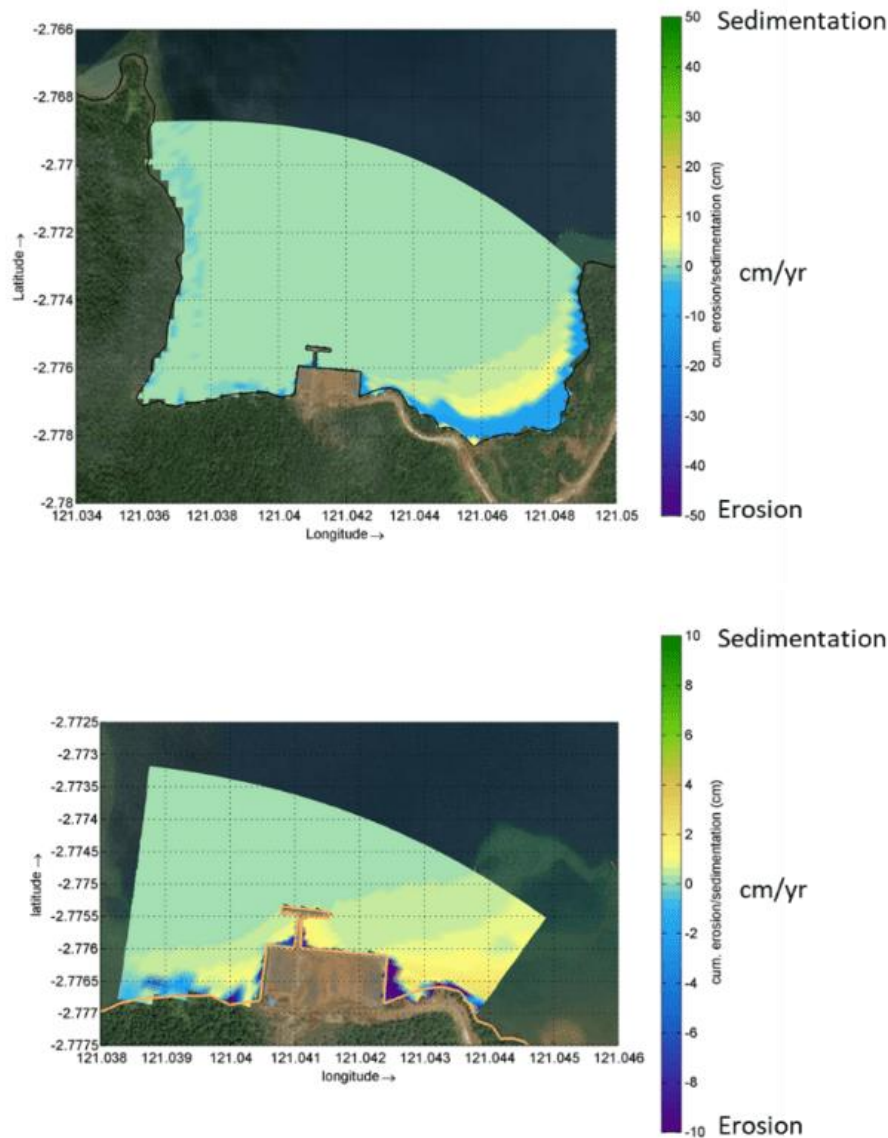


Figure 12. Yearly erosion and sedimentation patterns for Lampa Waters (above) and Lampa Port Waters (below)

4. CONCLUSIONS

The modeling results show that the tidal range at the Lampa Waters reaches 3.54 meters with a mixed-semi diurnal tide type. The results also indicate that the current pattern in the Lampa Waters is estimated to reach 0.5 m/s to 1 m/s. Meanwhile, for erosion/sedimentation around the location, it is found to be 3-10 cm/year.

Based on the study results, it is recommended to carry out periodic assessments of the existing port conditions, specifically the water depth at the ship docking area, to ensure that the water bed elevation matches the results of the numerical simulation that has been conducted.

5. ACKNOWLEDGEMENTS

The author would like to express sincere gratitude for the support received from the company where the author works, as well as the team that has collaborated and dedicated themselves fully to completing the work to the best of their ability.

REFERENCES

- [1] V. Afentoulis, A. Papadimitriou, K. Belibassakis, and V. Tsoukala, “A coupled model for sediment transport dynamics and prediction of seabed morphology with application to 1DH/2DH coastal engineering problems,” *Oceanologia*, vol. 64, no. 3, pp. 514–534, Jul. 2022, doi: 10.1016/j.oceano.2022.03.007.
- [2] Y. P. Sheng and H. Lee Butler, “Modeling Coastal Currents and Sediment Transport,” Princeton, 1982.
- [3] T. G. Andualet, G. A. Hewa, B. R. Myers, S. Peters, and J. Boland, “Erosion and Sediment Transport Modeling: A Systematic Review,” Jul. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/land12071396.
- [4] Y. Goda, “An Overview of Paradigm Shifts in Coastal Engineering-Wave Pressure, Wave Transformations, and Sediment Transport,” Yokohama, 2000.
- [5] A. Makar, “Coastal Bathymetric Sounding in Very Shallow Water Using USV: Study of Public Beach in Gdynia, Poland,” *Sensors*, vol. 23, no. 9, May 2023, doi: 10.3390/s23094215.
- [6] T. V. Karambas and A. G. Samaras, “An integrated numerical model for the design of coastal protection structures,” *J Mar Sci Eng*, vol. 5, no. 4, Oct. 2017, doi: 10.3390/jmse5040050.
- [7] M. C. Quick, “Sediment transport by waves and currents,” 1983. [Online]. Available: www.nrcresearchpress.com
- [8] A. Valsamidis and D. E. Reeve, “Modelling shoreline evolution in the vicinity of a groyne and a river,” *Cont Shelf Res*, vol. 132, pp. 49–57, Jan. 2017, doi: 10.1016/j.csr.2016.11.010.
- [9] K. Santoso, I. D. N. N. Putra, and I. G. B. S. Dharma, “Studi Hindcasting Dalam Menentukan Karakteristik Gelombang dan Klasifikasi Zona Surf Di Pantai Uluwatu, Bali,” *Journal of Marine and Aquatic Sciences*, vol. 5, no. 1, p. 119, Sep. 2018, doi: 10.24843/jmas.2019.v05.i01.p15.
- [10] B. Triatmodjo, “Teknik Pantai,” *Beta Offset*, Jan. 1999.